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Mould Temperatureand Mechanical Properties of Cast Aluminum-Silicon Carbide Composite

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Abstract Effect of mould preheating on the mechanical properties of stir cast Al-SiC has been studied. The silicon carbide particles ($83\mu m$) are washed with distilled water, oven dried at 100℃ for 2hours prior to use. The mould temperature is varied from 200-600°Cbefore the molten mixture is poured into it. Cast samples are divided into three groups, heated to 400°C normalized, annealed and quenched. These heat treated samples are then subjected to mechanical and structural analyzes. Results show that tensile strength and hardness decline with rise in mould temperature while elongation and impact strength increase. The highest tensile strength (~57MPa) is recorded for quenched samples at mould temperature of 200 °C and the lowest (~35 MPa) in annealed samples at the same mould temperature.The hardness increase considerably withquenched>normalised>annealed.

Keywords Mould Temperature, Aluminium-Silicon Carbide, Mechanical Properties, Heat Treatment

1. Introduction

With the development of industry and technology, the use of aluminum and its alloys due to its many technical propertiesadvantages, is on the increase worldwide[1]. The increase importance of aluminum and its alloys in recent years, have resulted in its high rate of consumption compare to iron-steel products as its now more in use in such areas as electrical, chemical, medicine, construction, automotive and aviation and their sub-industries[2-4].

Particulate-reinforced aluminum alloys are moreattractive than conventionalaluminum alloys for applicationsrequiring higher stiffness and strength. Reinforcementby particles or short fibers of SiC has proved to be advantageous since it offers composite materials with isotropic properties at low cost. Al-SiC composite is a material that has silicon carbide particles (SiCp)as filler inaluminum alloy matrix[5] resulting in lightweight, high thermal conductivity and controlled thermal expansion material. Al-SiCapplications include base plates for Insulated Gate Bipolar Transistors (IGBTs) for traction applications, large industrial equipment, electric vehicles, industrial robotics, welding machines and power supplies for medical imaging systems, as well as in Printed Wiring board (PWB) cores for defence electronics applications[6]. The introduction of SiCp in aluminium matrix has been shown to give good wear resistance and anti-friction properties with improved strength, ductility and stiffness[7].

Despite its excellent properties, Al-SiCp composites have detrimental effects owing to its poor wettability between molten Al and SiCp.In addition,brittle phases of Al_4C_3 and Si are produced due to[8, 9] undesirable reaction between the SiCp and molten Al . It has also been shown that current processing methods for Al-SiCp composites often produce agglomerated particles in the ductile matrix resulting in extremely low ductile material[10].Tensions and pores areformed in the matrix of these composites during solidification which are detrimental to ductility[11].

Most research in Al-SiCp has focused on characterizing the mechanical and wear properties of the composites by improving the wettability of SiC to Al matrix using appropriate wetting agents[12-14]. The study of Hashim et al (2001)[15] revealed that reduction in solidification time can improve the wettability while increase in volume fraction of SiCpgave an opposite effect.

The initial cast structure of a material is determined by its thermal gradient and the contraction rate during solidification. This makes it very important to define and distinguish the variables controlling the initial cast structure of the Al-SiCp compositebillets in their hot processability. Control of the initial cast structure could be achieved through control of casting variables namely rate of solidification or rate of diffusion at the solid-liquid interface, temperature gradient at the diffused solid-liquid interface and diffusibility of the soluble at the liquid and the solid interface[16-18]. These are all influenced by surrounding temperature (the mould temperature) condition and mould materials. The

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study by Oji et al[19] on the effect of casting parameters shows that mould temperature is the most significant factor influencing casting quality in terms of strength. The authors suggested further stated in this area so that inference could be reached for industrial application.

In the light of the above, this paper presents results of investigation into the effect of mould temperature before casting on the mechanical properties of AA1200aluminum alloy produced with the vertical continuous casting method. In the study, mould temperature is varied from 200℃-600℃ and the structural morphology and resulting mechanical properties of the Al-SiC composite are examined. The experimental design is purely based on authors' initiative while results of previous studies serve as a guide.

2. Methodology

The experiment was carried out by preparing composite samples using stir casting technique. Silicon carbide (10 wt %) of average composition shown in Table 1is washed with distilled water to improve wettability and enhance contact between the filler and matrix surfaces'. The washed silicon carbide is oven dried at 100℃ for about 2 hours.

Table 1. Chemical Composition of SiCp

Element	Si	K	Ca	Mn	Fe	Cu	C	others
% Comp	53	3	11	2.2	5.6	7	18	0.2

AA1200 aluminium alloy (see Table 2) received from Nigeria Aluminum Extrusion Company (NIGALEX), Oshodi, Lagos is placed ina crucible and heated to 800℃ for 1 hour in a muffle furnace. The homogeneous molten aluminium obtained is transferred to a stainless steel cup where SiCpare added and stirred properly with the aid of a glass rod. The mixture is then transferred to the furnace for further heating for about 2 minutes before casting. At each run the mould is preheated to a scheduled temperature between 200 and 600℃ before the mix is poured.

Figure 1. Cast Al-Si composite samples

Before heat treatment, cast samples (see Figure 1) are machined to standard sizes for each test .

Table 2. Composition of AA1200 Al alloy

Element	Si	Fe	Cu	Mg	Mn	Zn	Ti
% Composition	0.2041	0.46979	0.05936	0.03565	0.10493	0.00597	0.01750
Element	Br	Sn	Pb	Al			
% Composition	0.00046	-0.00463	0.00472	98.9500			

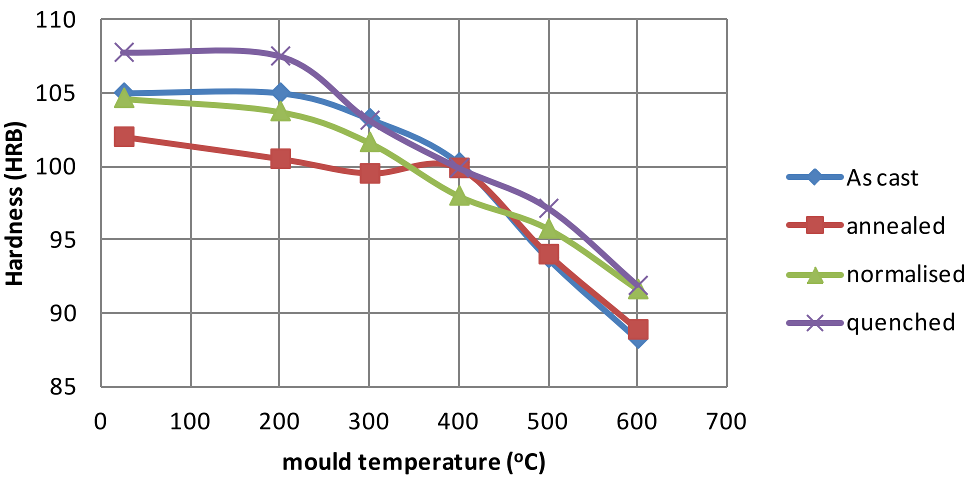


Figure 2. hardness response of Al-Si composite with mould temperature

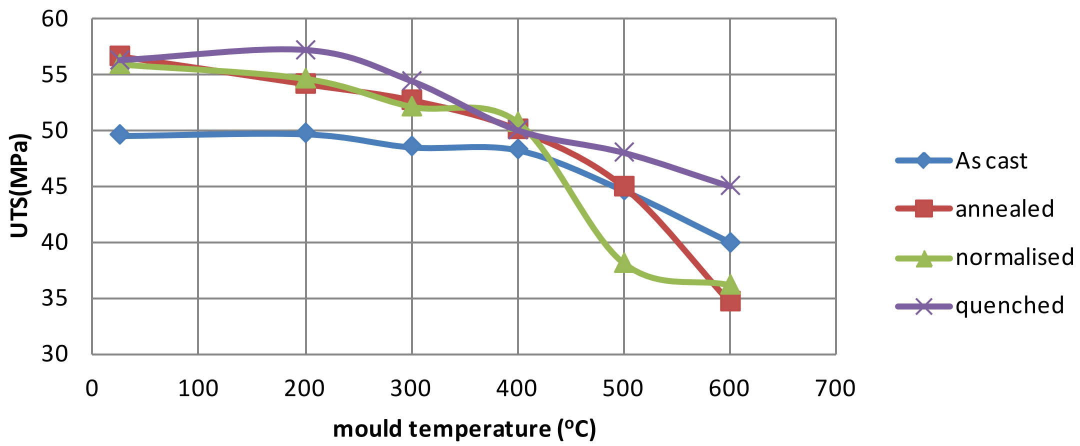


Figure 3. Variation of ultimate tensile strength of composite with mould temperature

Tensile sample dimension is 60mm long, 40mm gauge length, 5mm gauge diameter and 10mm outside diameter. Impact sample dimension is 60mm long, 10mm diameter, v-notch at 45° and 2mm deep at centre. Hardness sample dimension is 120mm diameter and 20mm thick. The heat treatment is carried out in a box-type furnace at 400℃ and samples cooled under three conditions namely; annealed, normalized and water-quenched. Hardness of cast samples are measured using the Rockwell hardness tester (model no E66236/142c) at a dwell time of 10 seconds. Tensile test is done using an M500 Universal testing machine. Impact test ofthe samples are carried out using theCharpy impact testing machine with model no: E742474.The samples surfaces' are ground to a smooth finish and polished to mirror-like for metallographic analysis. The mixture of sodium nitride and water is used as etchant and the samples are each etched for about two minutes to achieve a dull surface. The etched surfaces are viewed and picture taken using the Digital Metallurgical Microscope.

3. Results and Discussion

3.1. Hardness

The hardness test results for preheated mould and heat treated cast composites is shown in Figure 2. For all samples the hardness value decrease steadily with increase in mould temperature. Samples cast with mould at ambient temperature (32^{o}C) has hardness of HRC 105 which is superior to annealed(HRC102), normalized (HRC104.65), but slightly inferior to quenched sample (HRC107.75). However, heat treatment processing of cast samples shows a minimal effect over thatby mould temperature. The hardness increased considerably in the order quenched>normalised> annealed. The above results are in agreement with the study result on the mechanical properties of A713 alloy castings by Yadav and Karunakar (2011)[20].

3.2. Tensile Response

Tensile responses of cast and heat treated Al-SiCp composites are shown in Figure 3. Tensile strength of all samples is found to decrease with increase in initial mould temperature. The highest tensile strength (~57 MPa) is recorded in quenched samples at 200℃ mould temperature and the lowest of ~35 MPain annealed samples at this temperature. Oji et al (2011)[19] affirmed with 90% confidence interval that mould temperature has a significant effect on the ultimate tensile strength of aluminium alloys. Their results show that the ultimate tensile strength is maximum at low mould temperatures and the results in this present study are in agreement with Oji et al (2011). Investigation of mechanical properties of A713 alloy castings indicates that the tensile strength decreases with the increase in preheating temperature[20].

Tensile elongation responses of the cast composite increase with mould temperature for all heat treatment conditions (see Figure 4).Maximum tensile elongation (5.877%) is obtained in normalized specimen at 600℃ and followed by as-cast (5.268%)at the mould temperature. The minimum tensile elongation is observed in quenched specimen throughout the range of cast mould temperatures. This trend in tensile elongation response may be attributed to the fast growth of columnar grains against the wall at low mould temperatures giving low tensile elongation. However, at a higher mould temperature, there is reduction in the number of columnar grains while more equiaxed grains are produced in the matrix (see Plate 1). Some authors have affirmed that elevated mould temperature (low cooling rate) promotes uniform casting contraction and reduces stress concentration[21, 22] which enhances tensile elongation but detrimental to tensile strength. Tensile elongation of the quenched samples though inferior to other heat treated samples increases with mould temperatures. This may be attributed to the formation of hardening precipitates during quenching of Al alloys with resultant decline in tensile elongation. Tensile elongations of normalized samples increase steadily, with increase in mould initial temperature before casting. Normalizing allows for proper distribution of phases in the microstructure as clustered particles/ precipitates are rearranged so that the mechanical properties are improved. The annealed samples' tensile elongations do not differ significantly from as-cast samples' elongation responses. This may be as a result of the formation of equiaxed grain structure during prolonged cooling.

3.3. Impact Test Results

The impact responses of the cast composites are shown in Figure 5. The impact strength of quenched composites fluctuates with cast mould temperatures. Samples quenched, normalized and annealed show the same impact strength trend. Impact strengthsof samples increase between ambient mould temperature and 300 ℃ , decrease slightly and increases further to maximum at 600℃. Impact strength depends on several factors including the presence of notch, temperature, test sample thickness, inherent molecular structure of the alloy grade used and the morphology arising from the process conditions. However, changes in the geometry of the material could have a major effect on the toughness rating[29] (Swallowe, 1999). Fluctuations in impact energy data are indicative of difference in the surface conditions of the test samples and not generally due to microstructural changes. On the other hand, the presence of Al_4C_3 in the microstructure (see Plates 1-4) which has been reported to cause matrix embrittlement[28], may contribute significantly to the impact behaviour of the test material. For example in as-cast samples even distribution of the SiCp with the precipitation of Al_4C_3(Plates 1d and 1e) observed favour impact energy (compare impact strength of as-cast samples at different temperature). The results Yadav and Karunakar (2011)[20] report that impact strength declines with increase in mould temperature of cast A713 aluminumalloy. Annealed, normalized and quenched samples have similar responses as the as-cast samples.

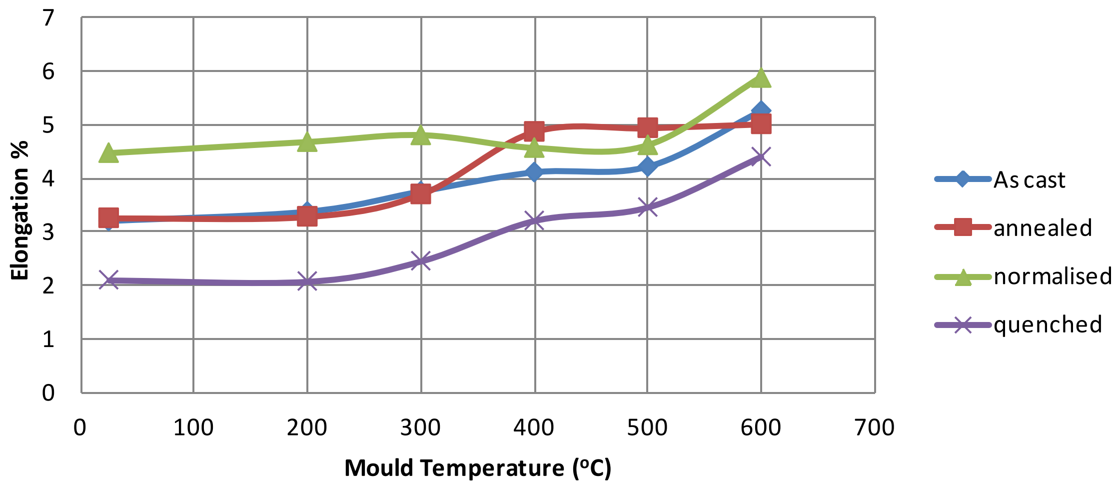


Figure 4. Variation of tensile elongation of Al-SiC composite with mould temperature

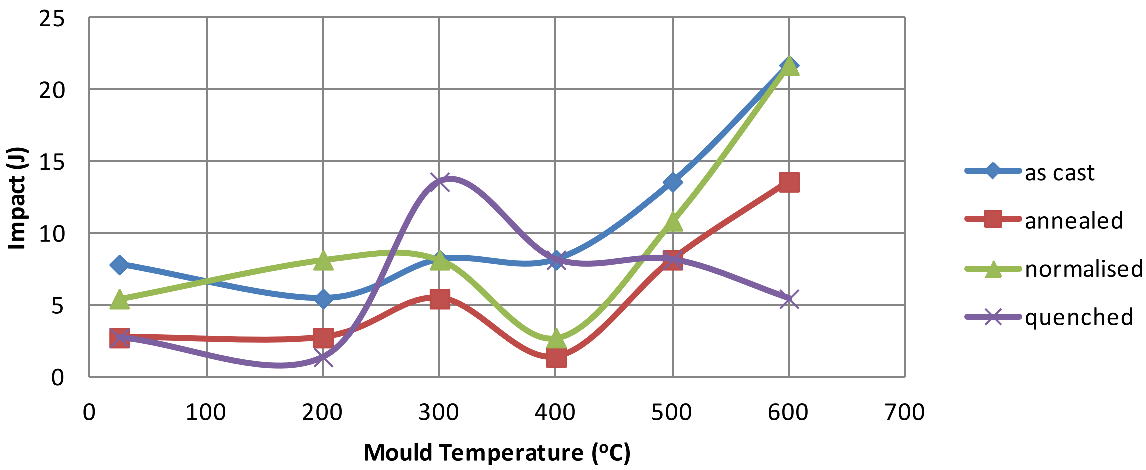


Figure 5. Variation of impact energy of Al-SiC composite with mould temperature

3.4. Microstructural Analysis

Micrographs of as-cast Al-SiC composite are shown in plate 1. These micrographs show the presence of SiC particles (dark phases) and Al_4C_3 in the dendritic structure of the alpha aluminium matrix. These are inferred from the colour of the etched phase under the light microscope as reported in literature[30] and previous works[23, 24]. The authors reported the formation of Al_4C_3 when pure aluminium and aluminium alloy is infiltrated SiC particles due to interfacial reactions. Iseki et al.[25] also reported that Al_4C_3 forms at the interface of the Al/SiC system. All microstructures show similar volume fraction of SiC particles located in the inter-dendritic regions of the matrix. It could be observed that at low preheating temperatures the SiC particles cluster along the in the inter-dendritic regions in a higher intensity than at higher temperatures, the intensity of cluster decrease as the preheating temperature increases. This may be due to prolonged time of solidification which leads to formation of Al_4C_3 surrounding the SiC particles found in microstructures of composites cast at high mould preheating temperatures (see Plate 1e). This may be the reason for a decrease in strength of these composites (see Figure 3). This is in line with other researchers who noted that Al_4C_3 is a brittle phasewhich forms agglomerates at the interface leading to degradation of composite strength[26, 27]. Another author posited that the presence of Al_4C_3 leads to matrix embrittlement[28]. Even distribution of the SiC particles and the presence of Al_4C_3 found in plate 1d and 1e favour tensile elongation and impact energy but are detrimental to tensile and hardness properties.

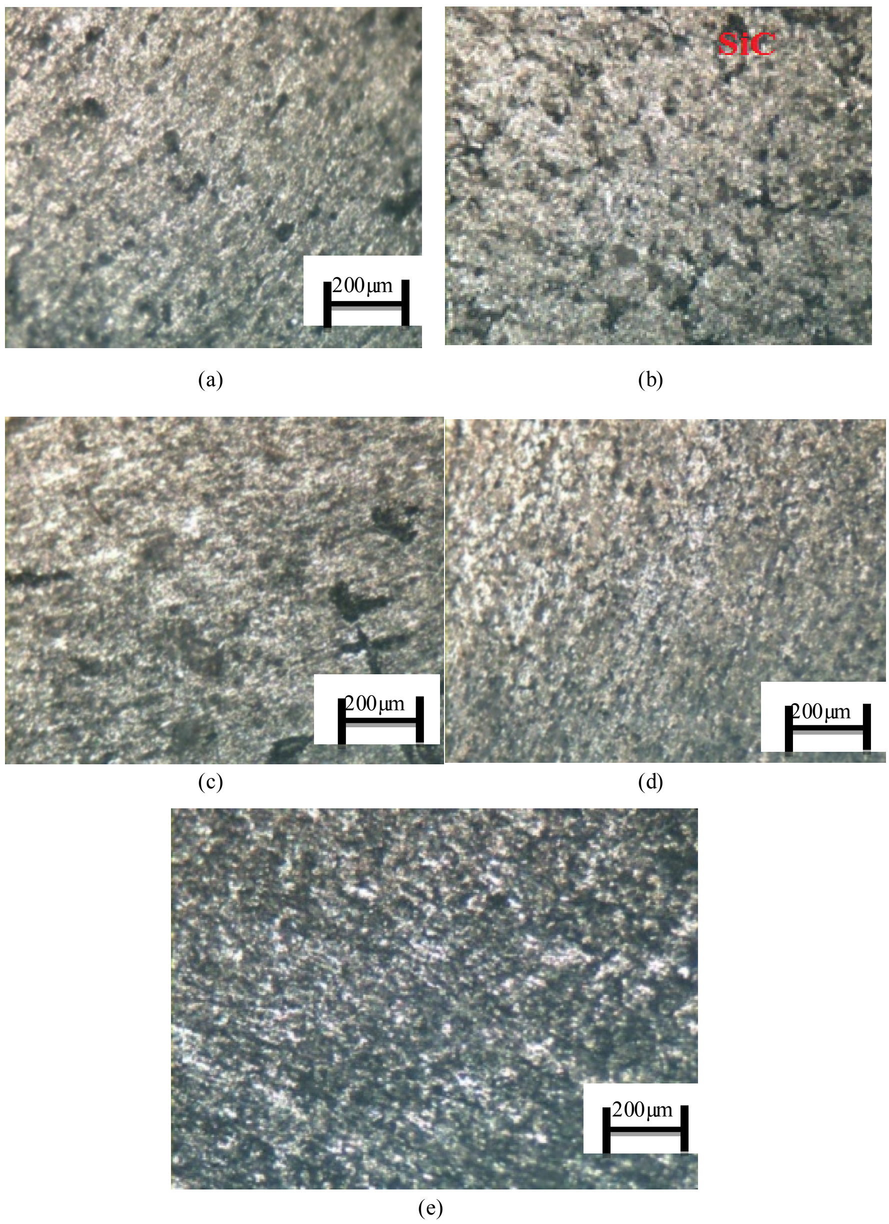


Plate 1. Microstructure of Al-SiC composite (As cast) (a) 200℃ (b) 300℃ (c) 400℃ (d) 500℃ (d) 600℃

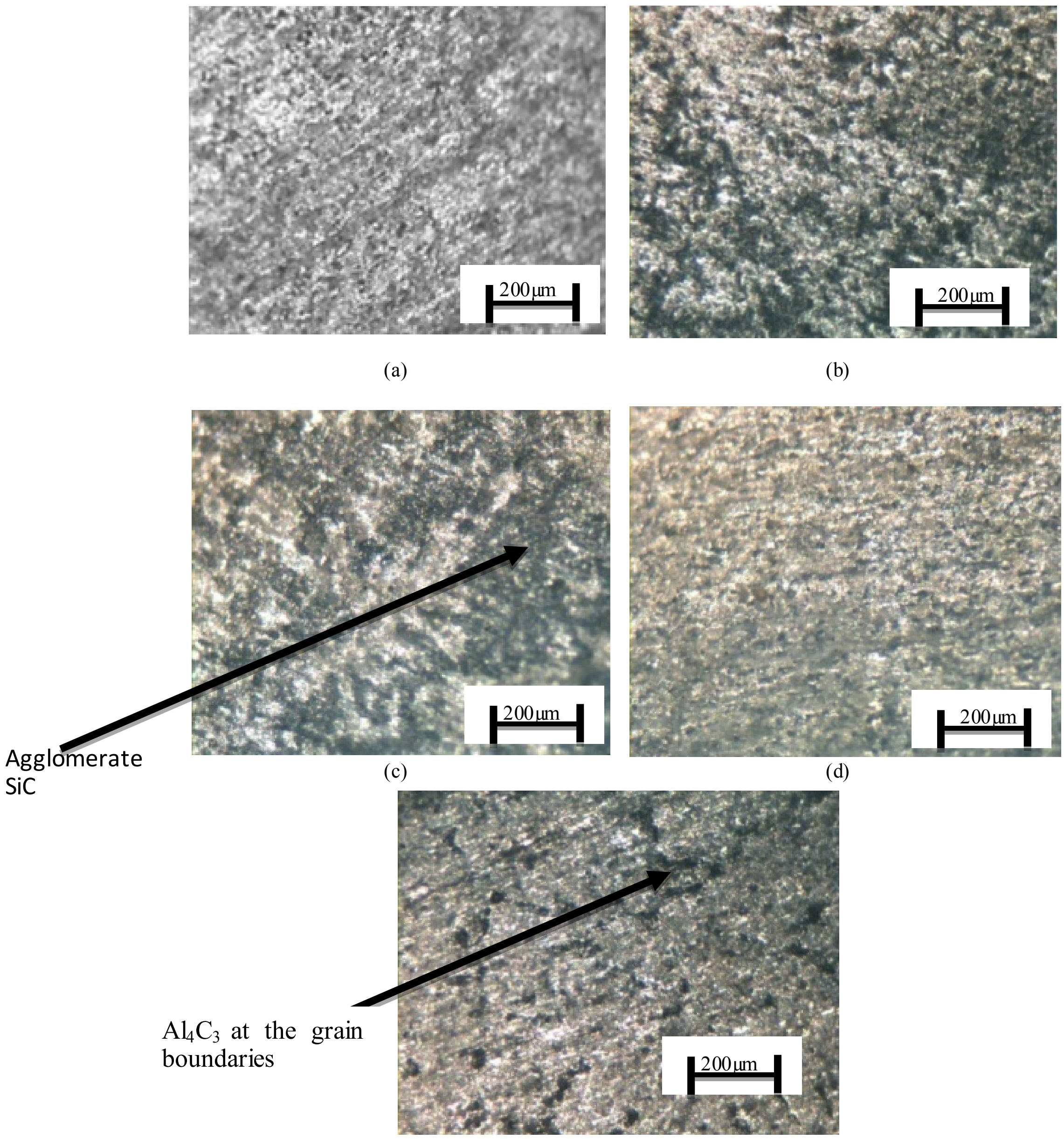
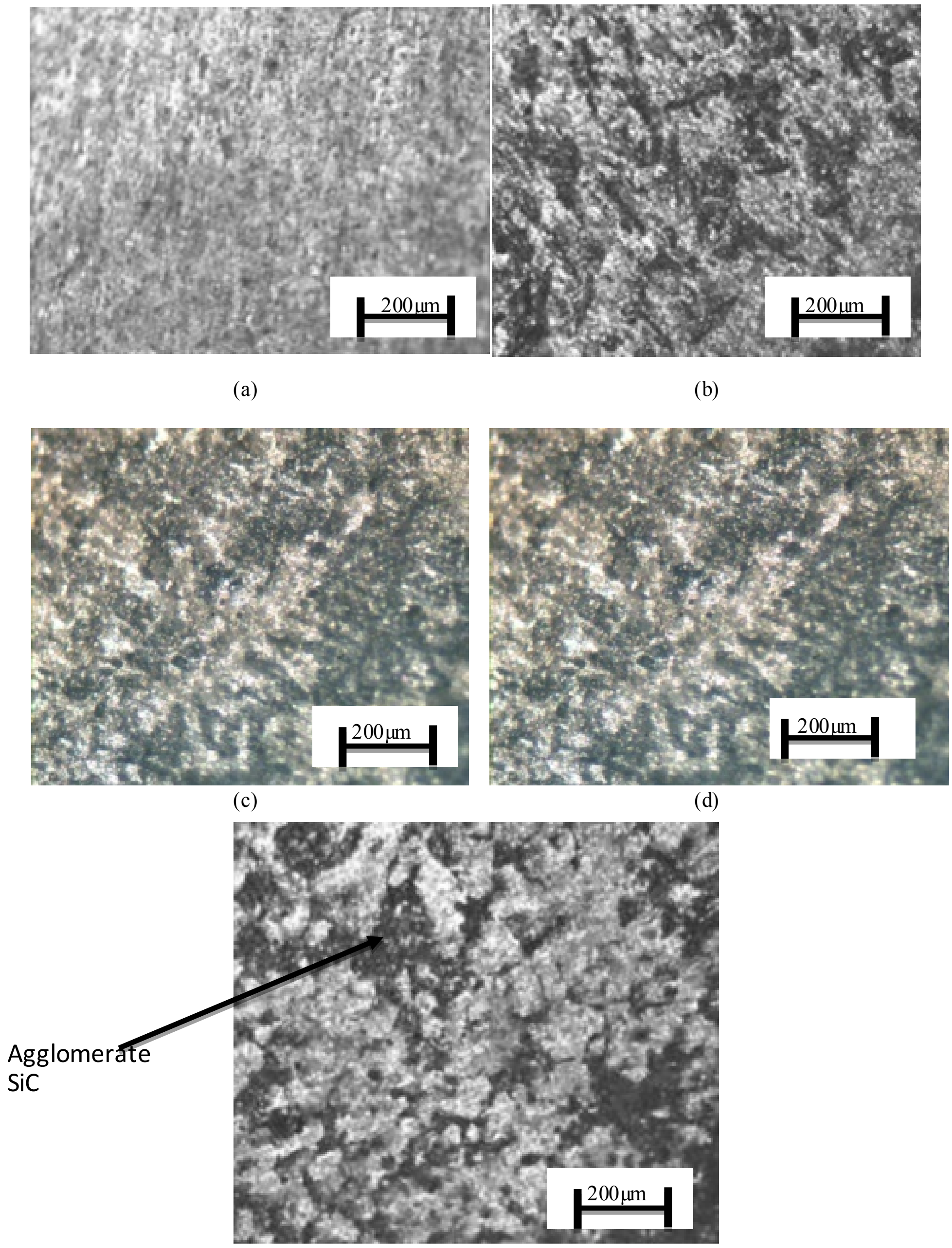


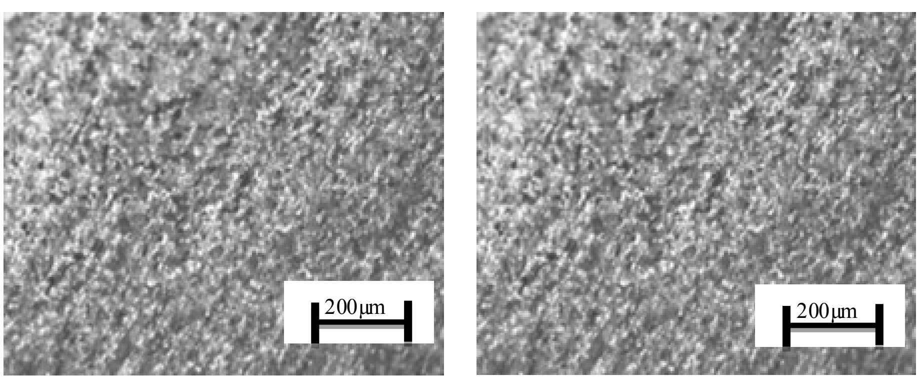
Plate 2. microstructure of Al-SiC composite (Annealed) (a) 200℃ (b) 300℃ (c) 400°℃ (d) 500℃ (d)600℃

Plate 2 is the microstructure of annealed Al-SiC composites after casting. All samples show a redistribution of the SiC particles. At 200℃ preheating temperature the cluster of SiC reduce leading to an increase in tensile strength (see Figure 3) but a decrease in hardness (see Figure 2). The cluster increased as the preheating temperature increases with higher volume fraction of Al_4C_3 appearing in plate 2d and 2e. Impact energy for annealed samples are lower than as-cast whereas tensile elongationremain constant. This may be due to the formation of Al_4C_3 in a higher volume fraction than in the as-cast condition. A similar behaviour is seen in plate 3 for all samples. In the contrary plate 4 shows a more coarse structure with pronounced distribution of the SiC particles and a reduction in volume fraction of Al_4C_3 in the matrix. The coarse microstructure and littering of the SiC favoured increase in tensile elongation and impact energy, however, tensile strength and hardnessremain the same.

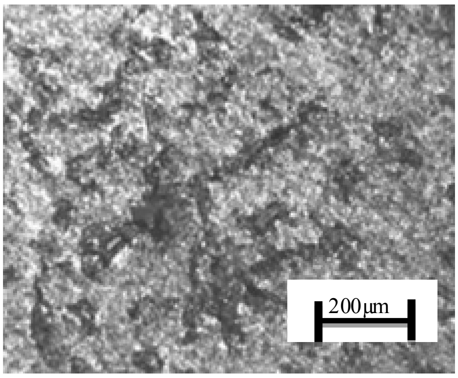


(a) (b) (c) (d) (e)

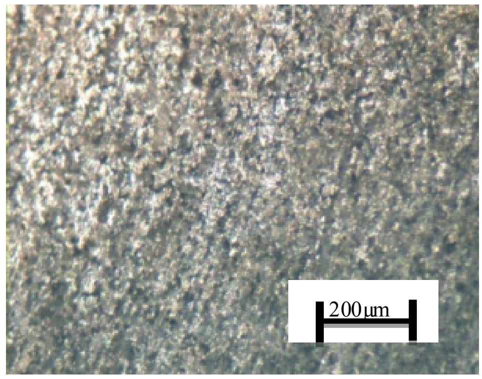
Plate 3. Microstructure of Al-Si composite (quenched) (a) 200℃ (b) 300℃ (c) 400℃ (d) 500℃ (d)600℃



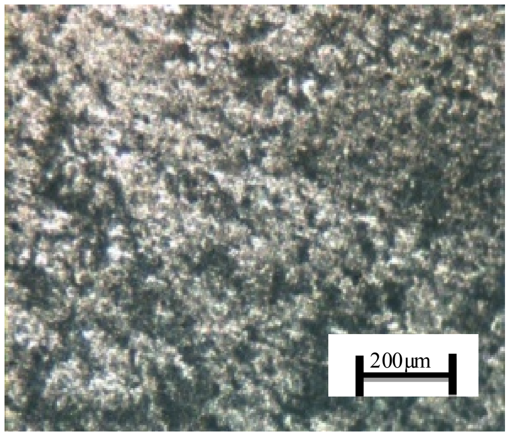
(a) (b)



(c)



(d)



(e)

Plate 4. microstructure of Al-Si composite (Normalised) (a) 200℃ (b) 300℃ (c) 400℃ (d) 500℃ (d)600℃

4. Conclusions

From this study, the following deductions can be drawn:

1. Mould temperature before casting has a significant effect on the mechanical properties of Al-SiCp composites
2. Increase initial mould temperature before casting is detrimental to hardness and tensile strength but improves both tensile elongation and impact energy of the composites.
3. Heat treatment of cast composite has significant effect on its mechanical properties. Quenched samples show superior improvement in hardness and tensile strength but not in tensile elongation and impact. Whereas normalized samples have better impact energy and tensile elongation.

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